Government of Karnataka

Landslides in Western Ghats and Coastal Karnataka:

Prevention and Mitigation Strategies

FINAL STUDY REPORT

Landslide Study Committee
Department of Forest, Environment & Ecology
Govt. of Karnataka

March 2021

Landslides in Western Ghats & Coastal area – Causes, Triggers and Solutions: Perspective based on the analysis of land use dynamics

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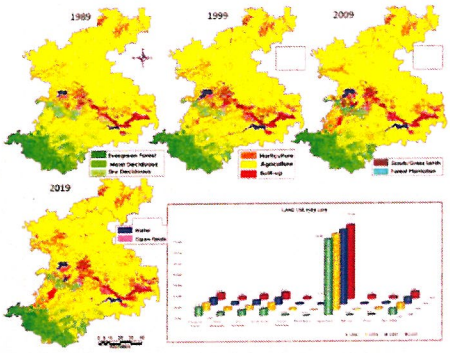
Landslides occur when masses of rock, earth or debris move down a slope. Mudslides, debris flows or mudflows, are common type of fast-moving landslides that tend to flow in channels. These are caused by disturbances in the natural stability of a slope, which is triggered due to high intensity rains with the extensive changes in land cover. Mudslides usually begin on steep slopes and develop when water rapidly collects in the ground and results in a surge of water-soaked rock, earth, and debris. Causes are either preparatory (factors responsible for unstable slopes) or triggering causes (events initiating landslides / mudslides). Thus, a landslide is a complex dynamic system with preparatory causes making slopes vulnerable to failure, while the triggering causes initiates the movement. However, each 'landslide' characteristically involves diverse processes operating together, often with differing intensity during successive years. The main trigger of landslides in central Western Ghats is due to high intensity or prolonged rainfall coupled with the large-scale land cover changes in the ecologically fragile regions. Slope failures are often triggered by anthropogenic activities with the high degree of unscientific developmental activities in vulnerable landscapes. Land use or land cover changes leading to land degradation and make hillslopes more susceptible to instability (or mass movement). The past several decades have witnessed intense disruption of forest cover, for alternative land uses (mushrooming of resorts under the guise of 'eco-tourism', mining, quarrying, monoculture plantations, agriculture, human settlements, roads, railways etc.) in mountains and hills with undulating topography. In such cases with the extreme meteorological events, such as high intensity rainfall leads to mudslides or landslides, leading to the loss of life with large scale destruction of property. Risk levels increase drastically in landslide prone areas with the accentuated anthropogenic activities. In addition to the terrain's geological property like shattered, fragmented and highly jointed rocks and topography like steep slopes, and factors contributing to slope failures are: (i) large scale land use changes leading to the removal of natural forests with native species, (ii) blockage of stream network leading to poor drainage network in the hillocks – due to changes in land cover (removal of vegetation or obstruction of drainage channels / streams and construction of resorts and villa's hindering the natural flow of water), (iii) destabilizing the slope through the removal of the basal support with steep slopes cut for linear projects (roads, pathways, etc.) and residential buildings near the base of the slope, (iv) changes in rainfall patterns – recurring instances of high intensity precipitation in short duration due to changes in the climate with the global warming, etc. The objectives of the current research pertaining to landslides in the Western Ghats and coastal regions are to (i) understand the land cover dynamics using the temporal remote sensing data, (ii) evaluating temporal forest fragmentation and its adverse effects on landscape connectivity and (iii) alterations in climatic regime due to global warming with the large-scale land cover changes in the ecologically fragile regions.

Land use dynamics in the ecologically fragile districts of central Western Ghats in Karnataka have been analysed using temporal (2005, 2019) spatial data acquired through space borne sensors (remote sensing data) along with the collateral data (historical vegetation map, the Survey of India topographic maps, long time precipitation data, etc.) and field data compiled using pre-calibrated hand held GPS (Global Positioning system). Likely land uses for the year 2033 using hybrid constrained Cellular Automata (CA) integrated with Fuzzy Analytical Hierarchical Process (AHP). ***The analyses reveal of escalating landslide vulnerabilities in the ecologically fragile Western Ghats, due to***:

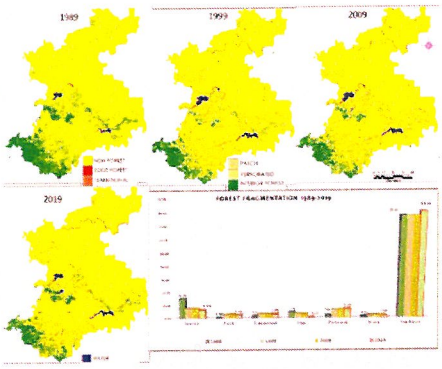
I. Belgaum district

- Landslide susceptibility due to large scale land use changes due to anthropogenic activities (unplanned developmental projects and encroachments) in ecologically fragile regions
- The land use analysis of Belgaum district shows loss of evergreen forest cover from 7.75 to 5.64% during 1989 to 2019

- The forest fragmentation analysis further reveals the loss of interior forest cover from 14.79 to 6.09 % (1989-2019) noticed with increase in edge, patch, perforated and non-forest cover.
- Modeling the likely changes shows an increase in built-up area by 5.2% by 2019 at the cost of agriculture and forest cover



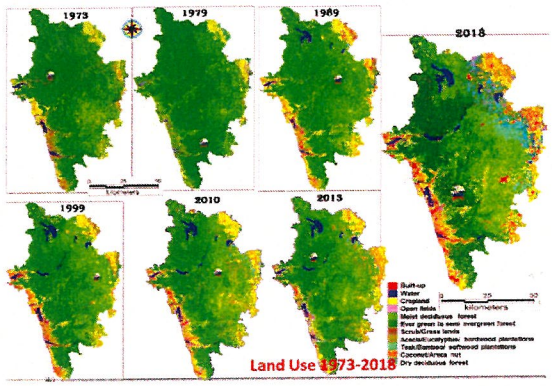
Land use changes in Belgaum

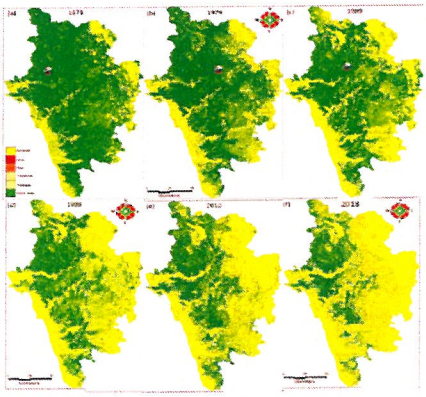


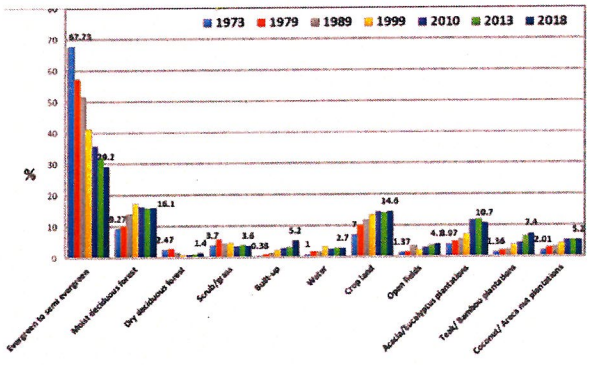
Forest fragmentation during 1989-2019

II. Uttara Kannada district

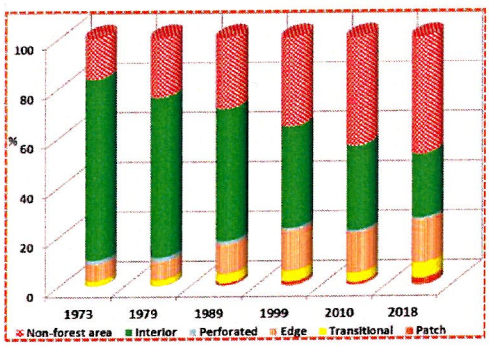
- The evergreen forest cover has declined from 68 to 29% and the area under human habitations have increased during the last four decades, evident from the increase of built-up area from 0.38 to 5.2% (1973-2018). Interior forest has lost from 73 to 22% with increase in edge, patch forest types.
- Simulated likely LU changes highlight the region will have 49% area under forest if the reserve forests are protected or else 45% will be the area under forest. The likely changes might be due to increase in agriculture, horticulture and plantations. The likely increase of built-up cover noticed as 6% and 8.5% by 2022 under two scenarios.





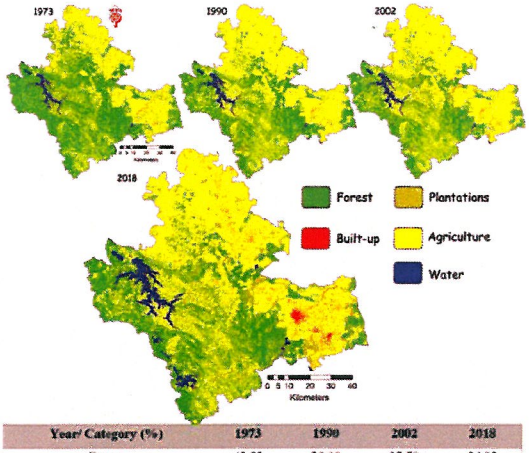


LU dynamics in Uttara Kannada 1973 to 2018

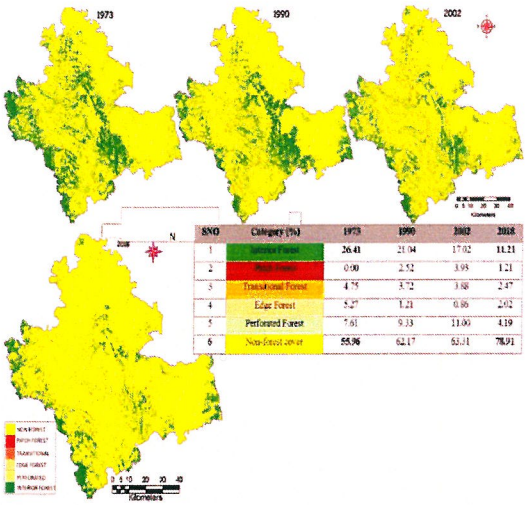


Fragmentation of forests 1973-2018

III. ShimogaDsitrict



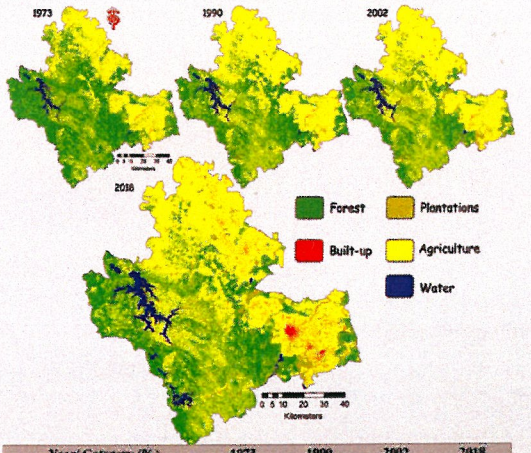
Year/ Category (%)	1973	1990	2002	2018
Forest	**43.83**	39.90	37.78	**34.02**
Water	1.91	4.53	4.57	4.29
Built-up	**0.63**	0.74	1.08	**2.35**
Plantation	9.46	25.15	26.36	**29.17**
Agriculture	44.14	29.68	30.21	30.17



SNO	Category (%)	1973	1990	2002	2018
1	Intact Forest	26.41	21.04	17.02	11.21
2	Patch Forest	0.00	2.52	3.93	1.21
3	Transitional Forest	4.75	3.72	3.88	2.47
4	Edge Forest	5.27	1.21	0.86	2.02
5	Perforated Forest	7.61	9.33	11.00	4.19
6	Non-forest cover	55.96	62.17	63.31	78.91

IV. Kodagu District.

- The spatio temporal land use analysis highlights the loss of evergreen cover and increase in built-up and monoculture plantation area. The region had evergreen cover of 40.47 to 24.17 % by 2019. The increase in resorts, buisldings, other infrastructure developments have resulted in the increase in built-up cover from 0.42 to 2.34%.
- The region had 31.3% intact forest and reduced to 19.7% with increase in non-forest cover and patch forest types.
- The simulation of likely changes for 2031 year depicts the region might have 23% evergreen forest with increase in built-up and monoculture plantation cover (49%).



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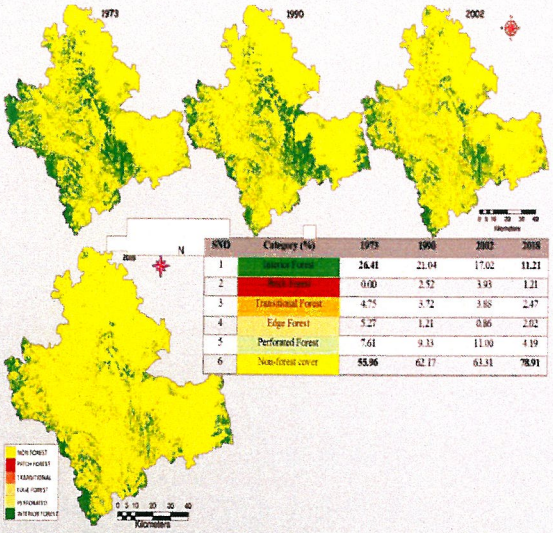

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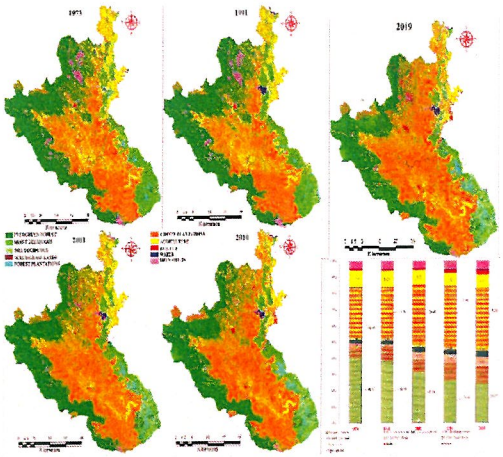
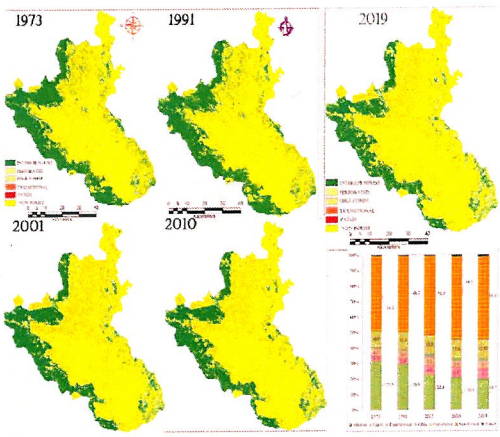


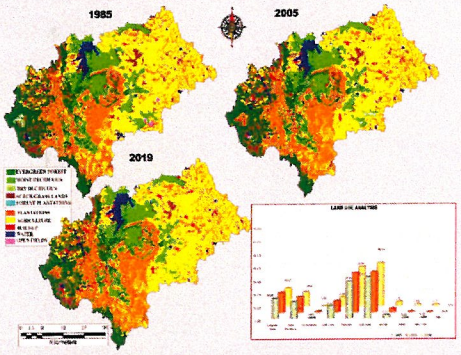
Land Use analysis of Kodagu from 1973 to 2019



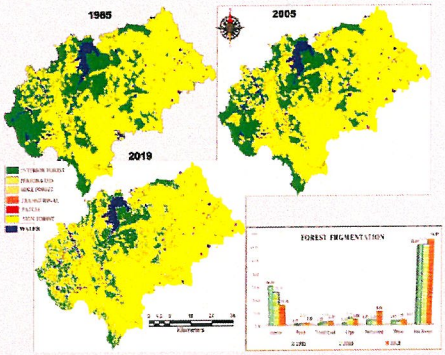
Fragmentation of forests 1973 to 2019

IV. Chikkamagalur District

- The increase of built-up patches from 2.55 to 5.16% (2019) is noticed with the loss of evergreen forest cover from 15.28 to 13.81%.
- Forest fragmentation analysis showed the decline of contiguous interior forests from 1985 to 2019 and domination of edge and patch forests. Koppa showed more fragmented forest patches with increased edge and patch forests. The extent of interior forest declined from 30 to 15% during 1985 to 2019. The non-forest cover type is increased from 61 to 65%.
- Forest fragmentation analysis showed decline in forests in Chikmagalur, Kadur, Sringeritaluks due to human alterations in between the forest areas. Decline of interior forest in Mudigere is due to increase in tourism and other developmental activities.



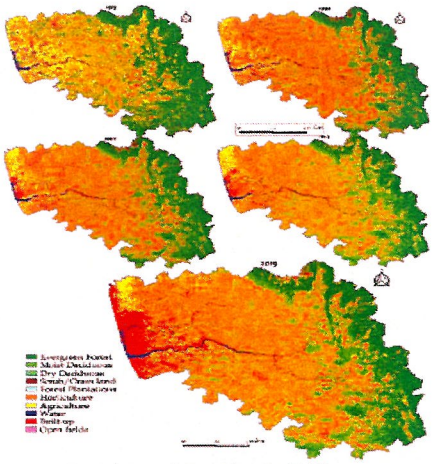
Land use dynamics in Chikmagalur



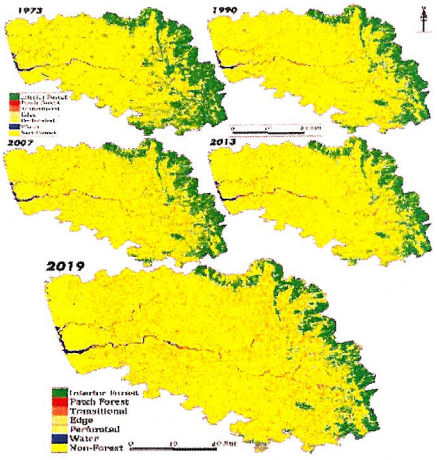
Fragmentation of forests during 1985 to 2019

VI. Dakshina Kananda

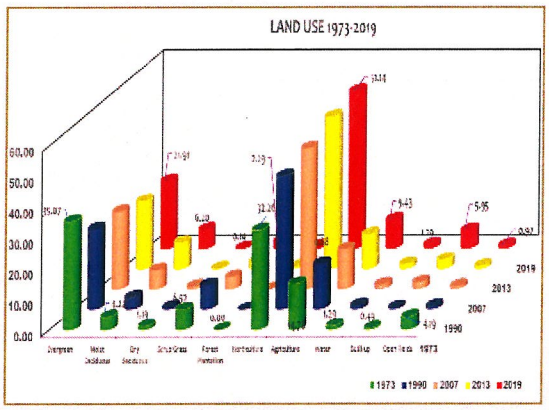
- The district had 35.07% (1973) evergreen cover, reached to 21.91% (2019) with an increase of horticulture from 32.3 to 51.14 %, and built-up cover from 0.49 to 5.95%
- The district had 27% interior forest cover with the least edge and patch forest types in 1973. The degradation has resulted in the loss of interior forest with an increase in the patch, edge forest, and non-forest cover. The interior forests are confined to the mountainous portions of the district and protected areas such as Kudremukh national park, Pushpagiri wildlife sanctuary.
- The increase in non-forest cover from 52 % to 68% has noticed in the last 5 decades

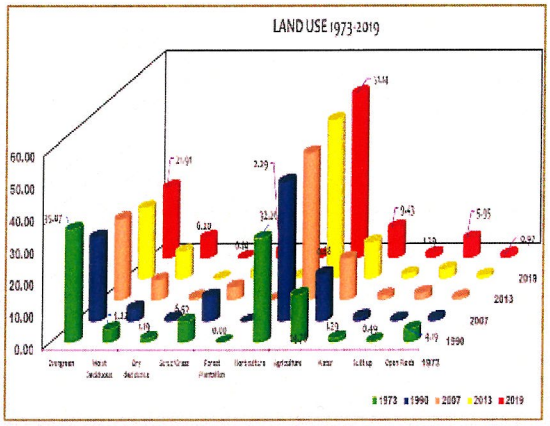


Land use dynamics in D.K.



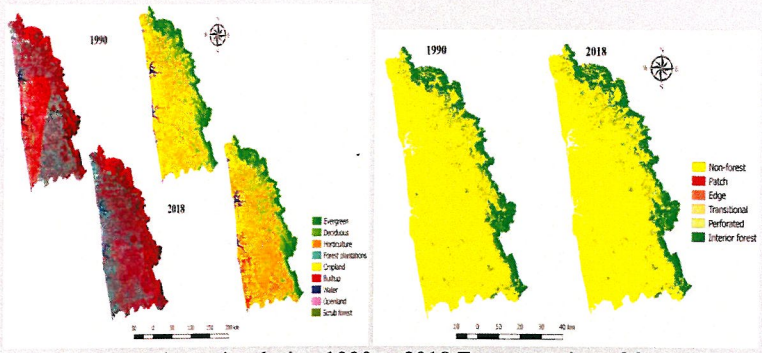
Fragmentation of Forests 1973 to 2019





VII. Udupi District.

- Area under forest cover i.e., evergreen and deciduous, has decreased from 11.63%, 10.47% to 11.38%, 8.37% respectively however, scrub forest increased from 1.85% (1990) to 2.71% (2018). Conversion of agricultural land to commercial use all along the major highways has increased the built-up area.
- The interior forest has decreased from 17.1% (1990) to 15.9% (2018) while non-forest areas has increased from 75.61% (1990) to 77.14% (2018). Transitional forest has increased from 1.8% (1990) to 1.91% (2018) indicating boundary between interior forest and non-forest has increased.



Land use dynamics during 1990 to 2018 Fragmentation of forests

Global warming with the burgeoning anthropogenic greenhouse gas (GHG) emissions (400 parts per million from 280 ppm CO_2 emissions of pre-industrial era) coupled with deforestation has altered climate, eroding the ecosystem productivity and sustenance of water, affecting the livelihood of people. Assessment of LULC dynamics in the Western Ghats using temporal remote sensing data show the decline of evergreen forest by 5% with an increase in agriculture, plantations and built-up area. The interior or intact forests has declined by 10% and are now confined to protected areas. The simulation of likely changes depicts the region will have only 10% evergreen cover and 17% agriculture, 40% plantations and 5% built-up.

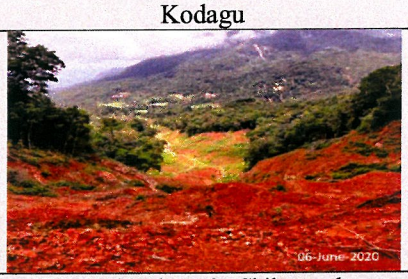
The southern Kerala (latitudes of 8-9^0) shows an increase in temperature from 0.5°C to greater than 1°C during the past 100 years, while the rainfall has declined by 250 mm and also the decline of rainy days by 2 to 4 days. Latitude 10-12 shows that the temperatures have increased between 0.25°C to 0.5°C in a century while rainfall has declined between 100 to 250 mm and decline of rainy days. The analysis indicated that the regions in the southern WG of Kerala, part of Karnataka (8-13^0) have witnessed large scale climate changes. The Central WG portions (Karnataka) shows less than 0.05°C increase, while the rainfall shows increasing trends close to 100 mm. The Northern portion of the WG latitudes (16-21^0) shows increasing temperature of 0.5 degrees and the rainfall has increased between 100 mm and just over 250 mm. This analysis demonstrates that LU has played a major role in moderating microclimatic conditions in WG over a temporal scale. The insights of the current research would help in evolving appropriate mitigation strategies towards sustainable management of forests and mitigate impacts of global warming.

IV. Destabilizing the slope through the removal of the basal support with steep slopes cut for linear projects (roads, pathways, etc.) and residential buildings near the base of the slope

Resorts in ecologically fragile regions - Unregulated tourism

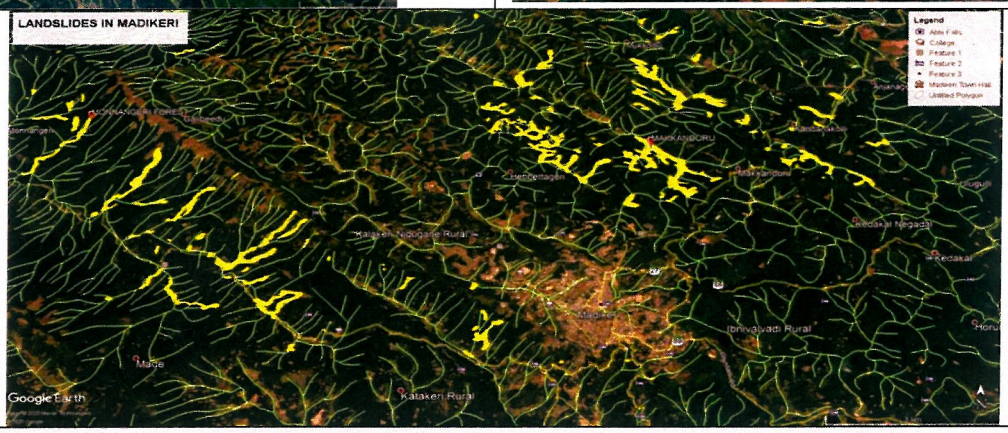
Stream blockage (Diversion for plantation)-Kodagu

Unscientific mitigation measures-Kodagu



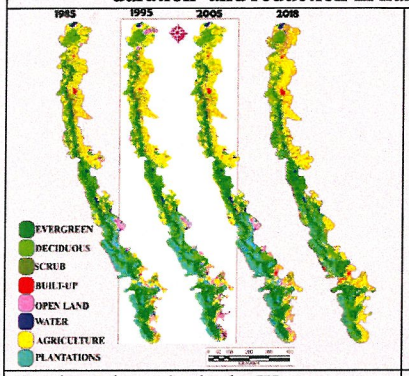
Stream blockage in Chikmagalur

II	Blockage of streams (hindering natural water flow) leading to poor drainage network in the hillocks – due to changes in land cover (removal of vegetation or obstruction of drainage channels / streams and construction of resorts, villa's, etc. • Landslide occurrence correlated with the stream blockages • Numerous buildings along the path of natural water flow

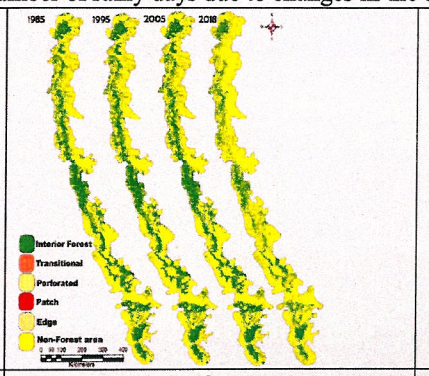


I. **Changing climatic regime due to deforestation, precursor to global warming**

- Large scale land cover changes leading to deforestation in the ecologically fragile Western Ghats, has contributed to an increase of **mean temperature of 0.5 ^{0}C and decline of rainy days**.
- Evident from changes in the precipitation patterns – recurring instances of high intensity precipitation in short duration and reduction in number of rainy days due to changes in the climate.



Land use dynamics in the Western Ghats



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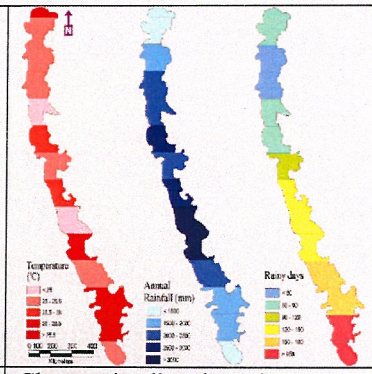
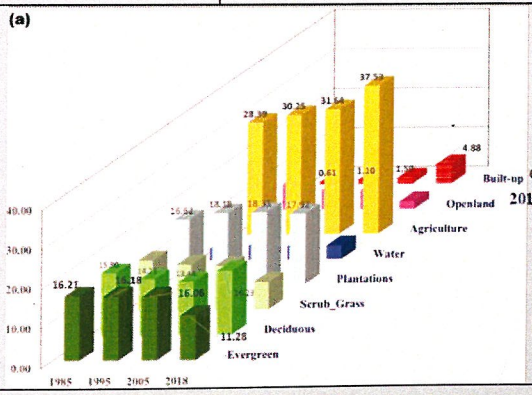
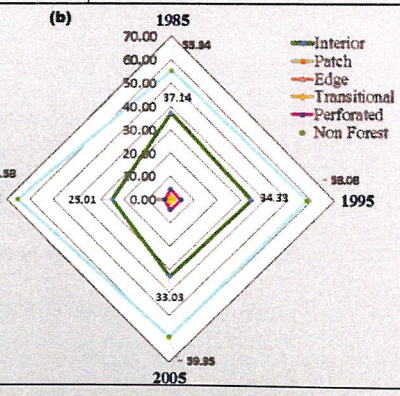


Changes in climatic regime





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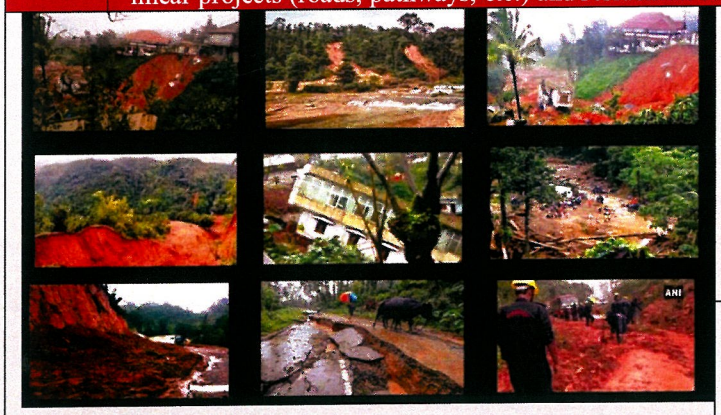

Resorts in ecologically fragile regions - Unregulated tourism

Stream blockage (Diversion for plantation)-Kodagu

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Stream blockage in Chikmagalur

A spate of landslides (during the past 15 years) in the coast – due to steep slopes cut, Locations of major landslides in coastal Karwar (overlaid on Google Image by star symbols. Also note the drainage network intensity in the hills. The shore of Arabian Sea all along from south of Baithkol hill is the Sea Bird Naval Base. The habitations are situated between the steep hills, the Arabian Sea, and the Kali River estuary)

Recommendations:(based on field investigations, data analyses and subsequent land use analysis):

1. **Identification of landslide prone regions:** Considering the level of devastations, landslide susceptibility mapping should be carried out to delineate potential zones of instability, to minimize the loss of human lives and damages to properties. If any indication of slope instability is noticed in an area which has major risk elements, the fact should be shared with the society in a proper way with the implementation of mitigation measures. This suggestion has two major implications.

(i) the risk posed by natural hazard must also be evaluated on priority considering the existing large scale environmentally unsound development activities in the region. This is well-exemplified by a series of natural hazards (landslides) in the region. Considering rainfall-intensity and changes in climate / hydrologic regimes (due to global warming) stochastic relationships must be explored to assess high-risk areas.

(ii) Secondly, with the successful establishment of relationship between rainfall and landslide activity, analysis of palaeo landslides would provide insights based on the past variation in rainfall patterns. Equally, such relationships aid in predicting changes in mass movement activities based on modelled regional impacts of global climate change.

2. **Arresting deforestation:** Analyses ofland use dynamics highlights of widespread removal of native vegetation in all districts of central Western Ghats. Tree cutting amounts to removal of a protective mantle. Moreover, after interval of some years when the root network disintegrates the compaction of soils and rocks by root mass weakens causing slope failure. The hollows created by stump and root disintegration become a major cause for water seepage into the soil and trigger off landslides during spells of heavy rainfall.

3. **Planting of native vegetation on hilltops and slopes:** The roots of the native vegetation, especially of certain chosen tree species, can act as good soil binders, thereby providing slope stability. The removal of trees (with deep tap roots) and subsequent taking over of secondary vegetation, planting of monoculture species on hill tops by removing earlier natural tree cover, most of them with shallow roots has reduced the soil binding properties. At present many hill tops are barren or with highly inadequate tree cover.

   Restoration of vegetation cover: A replanting programme should be undertaken giving priority for strong and deep-rooted species which check erosion and withstand water-logging. *Pongamiapinnata, Calophyllum inophyllum, Ficus racemes, Thespesia populnea, Barringtonia* spp., *Terminalia arjuna* etc. may be considered for lower slopes bordering the estuarine areas. Middle and upper slopes in landslide prone areas should be planted with tree having lower biomass but stronger and deeper root networks. Minimum of 350 trees/ha would be ideal number for the hills. Location specific species of

the natural vegetation should be given priority. The general practice of afforestation with the exotic species of monoculture of trees has to be discontinued in all hazard zones.

Enhancing the scope of VFCs: The scope of the already existing village forest committees may be expanded to landslide/natural resource management as well. Necessary awareness and training programmes may arranged for members of VFCs in landslide prevention and management.

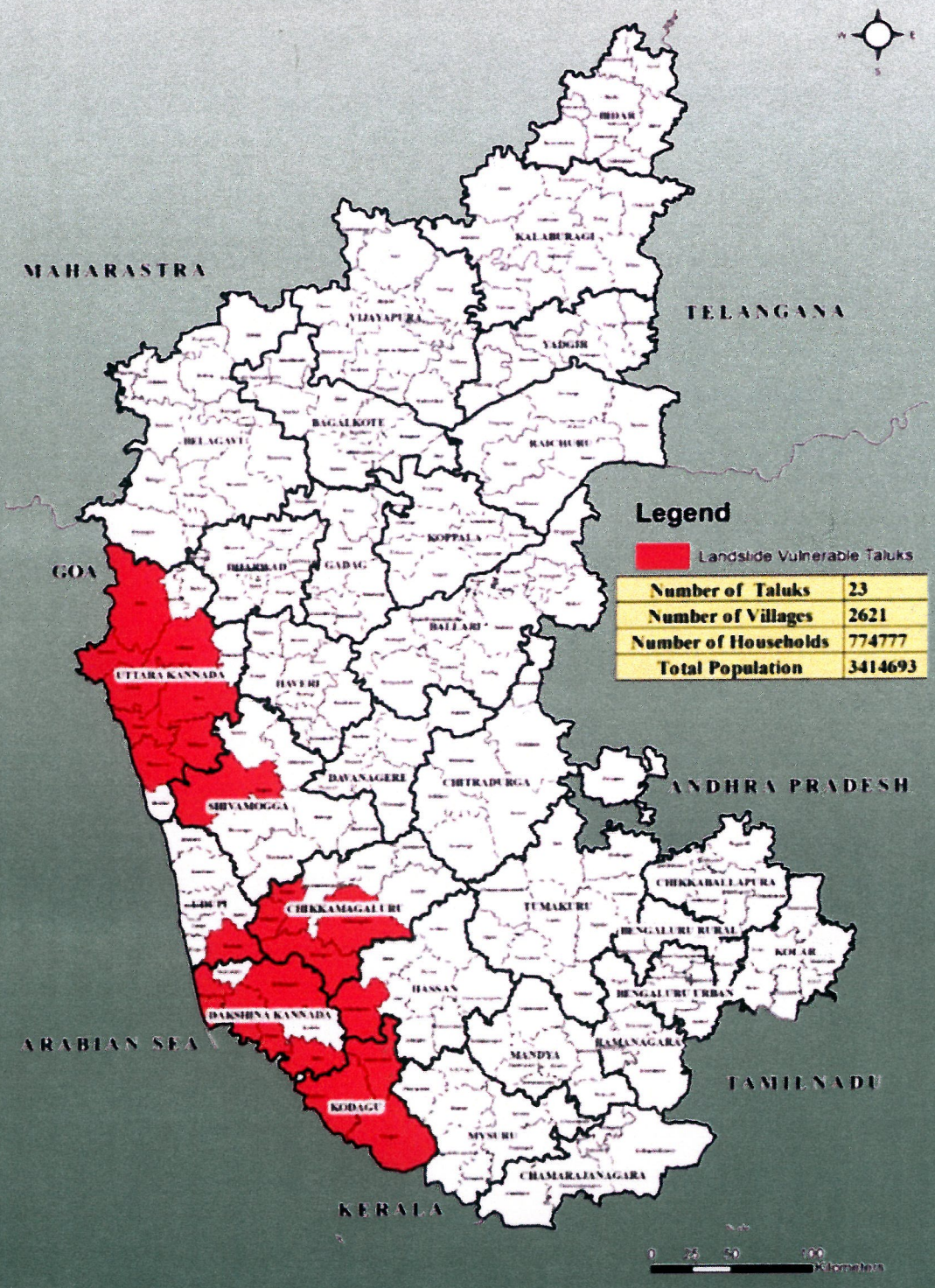
4. **Enhance structural stability of fragile hills:** Apart from reforestation of barren hill slopes and hill tops, sealing of cracks, slope-grading, proper drainage measures, soil reinforcement using geo-grid and biotechnical measures must be done. However, appropriate selection of these measures along with their design is only possible after an in-depth geological and geotechnical study of the slide area.
5. **Restoration of natural drainage network:** Alteration in hydrological regime due to changes in drainage network consequent to deforestation due to unplanned anthropogenic activities. Inappropriate locations of human habitations on the first and second order streams has hindered the natural water path. Heavy pressure of rainwater along the natural water path (within the hill) removing all blockages and resulting in mudslide and collapse of houses.
6. **Eco-restoration of Drainages and buffer zones:** Natural drainage patterns should be investigated and maintained to ensure free flow of water without any blockages. Riparian plant species or stream-side species are to be promoted for stream-bank protection, flood plain protection, to enhance the water retention capability and ecology.
7. **Improving drainage connectivity:** The sustained rainfall of many days would enhance the pore water pressure. This with lateral pressure due to swelling of oversaturated clay rich horizon has set the driving force resulting in burial of houses, human's displacement and loss of properties.
8. **Discouraging monoculture plantations:** The land given to commercial plantations in ecologically fragile regions should be taken back and the afforestation has to be carried out with the native species of flora according to suitably designed planting programmes.
9. **Restrictions on large scale developmental projects particularly in ecologically fragile regions in Central Western Ghats.** The implementation of large number of mega projects in ecologically sensitive regions, has already surpassed the carrying capacity of the region and further implementation of any mega projects would prove detrimental with the recurring instances of disasters leading to the loss of life and property. The regions prone to hazards needs to be mapped and designated as hazard hotspot.
10. **Banning of large scale illegal quarrying of granite stones and mineral mining in ecologically fragile regions of central Western Ghats,** considering the hazards proneness of the region and presence of ecologically sensitive pockets.
11. **Banning soil and rock mining in ecologically fragile hills-** Landslide prone areas should not be leased out for soil or stone removal. All illegal mining and quarrying must be stopped immediately.
12. **Restrictions on slope cutting and deep excavations:** Natural slope of hills have been cut in many locations for linear projects. Toe support of vulnerable hills has been cut by the residents for housing, resorts, etc. There has been also digging of the hill for soil. This necessitates **stringent regulations on slope cutting.** Indiscriminate slope cuttings must be strictly regulated and engineering or ecological solutions to be deployed depending on the level of hazard. Bio-protection is by far most important. Quarrying for stones and soils to be strictly regulated in vulnerable regions prone to landslides.
13. **Need to investigate the suitability of human habitations in regions prone to landslides and rehabilitating all affected families** at appropriate locations without affecting their current livelihood dependence.
14. **Considering the hazard proneness of the region it is necessary to set up 'Disaster management centre (DMC)'** in each district of central Western Ghats to assist in regional planning, management of disasters and also to assist the administration in rehabilitation measures in case of eventualities. Also, need to setup a **seismic monitoring cell (within DMC)** in the district to assist the district administration in the predication and mitigation measures. Disaster management centre shall house

seismic monitoring cell and shall have the state of the art gadgets to predict calamities due to natural as well as human induced causes.

15. **Setting up special packages to restore ecosystems in all districts affected by recurring disasters (landslides):** Many districts in central Western Ghats have **transgressed its limits of growth, beyond the carrying capacity** - Series of landslides consequent human tragedies and property loss is the indication of the lack of integrated approaches in planning and the region has crossed the thresholds of carrying capacity. Large scale land cover changes have resulted in alterations in hydrological regimes evident from the conversion of perennial streams to seasonal streams, enhanced siltation in the catchment evident from increased sedimentation in reservoirs in recent years. Many large-scale projects implemented already in this region have played significant role in degradation the ecosystems which have been affecting the livelihood of local people. **These projects shall also make provision to provide a recurring grant to sustain the proposed Disaster Management Centre and also for research in these regions.**
16. **Constitution of Western Ghats Authority to regulate development within carrying capacity and to ensure integrated sustainable management of natural resources:** Numerous development projects implemented during the post-independence period and commercial establishments have transgressed the region's ecological carrying capacity. Need to formulate measures for safeguarding ecological stability of the region as well as recommend cluster based developmental path that are compatible with the rich biodiversity, natural resources availability and ecological fragility of the region.

KARNATAKA STATE NATURAL DISASTER MONITORING CENTRE

LANDSLIDE VULNERABLE TALUKS



Landslide Study Committee

Department of Forest, Environment & Ecology

Govt. of Karnataka